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Climate change and water loss in the Kinneret drainage basin

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ABSTRACT

Long-term data sets of headwater river discharges and precipitation record in the northern part of the Kinneret drainage basin were compiled and analyzed. Previous conclusions related the headwaters discharge decline to anthropogenic enhancement of consumption. Wider and deeper search of the regional balances confirmed enhancement of gravitating water loss in the Hula Valley. The Hula Valley soil properties of Field Capacity, Bulk Density and Wilting Point confirm the potential loss of gravitating water during periods of dryness due to Climate change through preferential pathways.

1. Introduction

Until the late 1950's, the Hula Valley (altitude: 62–70 m ASL) was covered by the shallow Lake Hula, and 3500 ha of swamps of Lake Kinneret Headwaters include three major and several smaller "other" river flows from the Hermon Mountain region and the Golan Heights located in the northern part of the Kinneret drainage basin (Fig. 1): Snir (Hatzbani), Hermon (Banyas) and Dan. In-Situ Discharge recorded measurements at the location of Welling up of Snir and Hermon rivers are not available whilst that of Dan River exists (1939–present). Headwater rivers join into one river Jordan which is crossing the Hula Valley in two major canals ("Western" and "Eastern") and several intermediate trenches used as drainage collectors or water supply for irrigation. All those canals terminated jointly at the southern end of the Hula Valley (Canals Meeting Point) into one "Mountainous Jordan" at the south end of the Hula Valley (61 m ASL), which flows 15 km southward downstream into Lake Kinneret (210 m BSL). A major part (the rest is removed western) of the Hula Valley outflow is monitored at the Huri Bridge Station located app 4 km south of the "Canals Meeting Point". Minor part of the Hula Valley external input of running water is removed western and excluded from the Jordan flows as measured in the Huri Bridge Station.

During the 1950's, old Lake Hula and the swampy northern wetland were drained and more than 6500 ha were turned over to agricultural use – to serve as an income source for residents of the northern part of Israel. For 40 years the dried area was successfully cultivated and agricultural products (mostly cotton, corn, alfalfa) were economically produced and Hula Valley-originated nutrient fluxes did not threaten Kinneret water quality. As a result of inappropriate agricultural management and irrigation methods, during those 40 years, the drainage canals were blocked, soil structure was degraded, dust storms and Rodent bursts occur frequently and nutrient threatened Kinneret water quality. The underground water table declined and subsidence of soil surface was observed (7–10 cm/year). Outbreaks of underground peat fires occurred frequently in summer and vast amounts of water were needed for extinguishing, which enhanced nutrient flux into Lake Kinneret.

Ten percent of the total drained area, (approx. 500 ha), located in the middle part of the valley (lowest altitude), experienced extreme soil deterioration and subsidence which made it impossible for maintaining beneficial cropping, and these 500 ha were neglected and not cultivated. The threat to declining Kinneret water quality was enhanced. A reclamation project entitled "Hula Project", was proposed and implemented (1990–1997). The project objectives were aimed at reducing nutrient fluxes from Hula soil while continuing the economical utilization of the land by partial usage modification from agriculture to ecotourism. The Hula Project included increasing the level of soil moisture by elevating the water table, changing the irrigation system and renewing the hydrological system of the valley: rennovation of 90 km of drainage and water supply canals; creating a new shallow Lake Agmon (0.45 m average depth; 110 ha area) to be operated as a rich nutrients water collector integrated within the drainage system and serving as an eco-touristic item. A plastic sheet (4 mm thickness) was placed vertically (0–4.5 m) along 2.8 km, south of the Lake Agmon crossing along the East-West axis of the valley to prevent underground southern infiltrated flows.

A report on regional water balances in the Kinneret Drainage Basin during 1963–2002 was published (Schanzis, 2002). A significant

Abbreviations: ASL, Altitude Above Sea Level; BSL, Altitude Below Sea Level; mcm, Millionj Cubic Meters; mcm/y, Million Cubic Meters per Year; m^3/y, Meter Cube per Year; BD, Bulk Density; FC, Field Capacity; WT, Wilting Point; g/m^3, gram per meter cube; %w/w, Weight per Weight Percentage; V%, Volume percentage; WL, Water Level; ET, Evapo-Transpiration; Alfa (α), (see text); mm/y, mm/year (rain); m^3/s, meter cube per second

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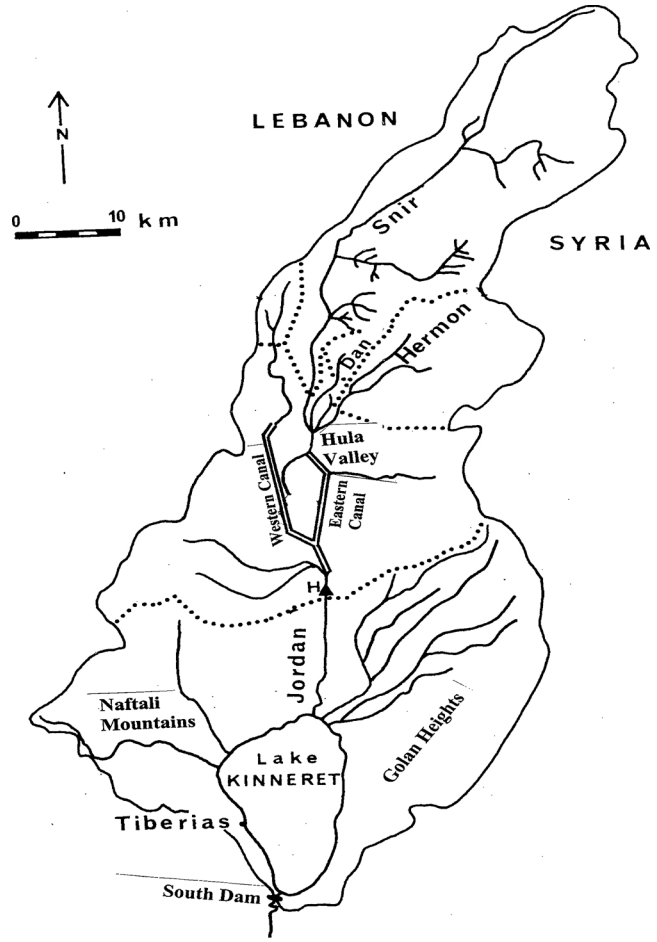

Fig. 1. Kinneret Drainage Basin Major and other rivers are Charted: Hermon (Banyas), Snir (Hatzbani), Dan, and "others" H = Huri Bridge.

Table 1
Annual (1999) Water Consumption (mcm; $10^6\,m^3$) in Upper Galilee Region.
Data Source: I. Chen, Galilee Representative, Agricultural Ministry; N. Schatz, Upper Galilee Municipality-Agricultural Corporation.

15 Consumer	Total Area ($10^3\,m^2$)	$m^3/10^3\,m^2$/y	Annual Consumption (mcm/y)
Deciduous Fruit Trees	38504	700	27
Citrus Fruit Trees	6641	700	4.6
Sub-Tropical Fruit Trees	10019	1100	11
Other Orchards	1000	650	0.7
Irrigated, Field Crops, Vegetable	99000	500	49.5
Rain-fed Field Crops	0	0	0
Aquaculture	4000	1800	7.2
Milk Cattle Forage	3273	500	1.6
Meat Cattle Fooder	6378	100	0.6
Domestic Supply	0	1	1.04
Total		790	103.2

increase of water consumption annually in the drainage basin was suggested and presented in this document. Official information concerning water consumption in the northern country region indicated a discrepancy of results as exemplified in Table 1: 200 mcm/y and 103.2 mcm/y presented by Schanzis (2002) and Agriculture Company, Upper Galilee Municipality, (personal communication) (1999), respectively.

The Regional annual water balances have indicated a gap between measured inflow resources and actual summation of catchment outflows. This gap was suggested to result from an increase of human consumption in the drainage basin and evoked a conclusive precaution. Evaluation of the regional net-work conduction capacity indicated this option as wrong.

The paper objective is aimed at analyzing the impact of climate change on the hydrological conditions within the Kinneret Drainage and the water loss potential.

2. Methods

The present study is the outcome of innovated evaluation of available long term data record. The information was compiled earlier by several authorities and recalculated comprehensively here. Moreover, additional information about hydrological features of the peat soil was incorporated. The Hydrological system structure of the Kinneret drainage basin emphasizing the Hula valley was widely documented (Gophen, 1995–2006; Gophen et al., 2014; Gophen, 2006). The Hydrological information was taken from the Annual Reports of the Israeli Hydrological Service (1970–2002). Relevant information, mostly with regard to the Properties of the Hula Valley soils, was compiled from published literature (among others: Levin, 1970; Litaor et al., 2011/12; Schallinger, 1970; Ravikovitch, 1992). Data source of River Dan Discharge, Precipitation (Dafna, northern region of the Hula Valley) is Agricultural Guidance Service, Agricultural Ministry (M. Peres). Water Consumption data supported by the Agricultural Association of the Regional Municipality and Northern Office of the Agricultural Ministry (N. Schatz, I. Chen) and TAHAL, Water Planing for Israel, Co. Ltd. (1989–1996).

3. Results

Recent studies documented underground water migration in the Hula Valley (Babd et al., 2017). Water and nutrient capacities and optional migrations in the Hula underground were previously documented (Gophen, 1995–2006; Gophen, 2006; Gophen et al., 2014; Pain and Gophen, 2011/2012). The high level of the Hula peat soil porosity is the result of two major types of free spaces: Micro scale of convoluted capillarity and Macro scale of preferential pathways of cracks and tunnels produced by soil shrinkage (cm magnitude diameter). Tunnels, crakes or underground free spaces are occasionally exposed by drilling, dug-out, trenches or ditches (Photo 1). The capillary hydraulic conductivity of the peat soil is very low but that of the preferential pathways is a free flow. Two distinct types of water migrations existed: Capilarity trait mostly limited to the upper few meters of the soil section and free flows within the preferential pathways. While water migration

Photo 1. Trench digging (3 m) in the Peat Soil exposed an underground flow.

of the first type is driven by capillarity forces, the second type is ruled by gravity. Nevertheless, soil-water relations in the upper layer have an impact, among other factors, on the flow rate of the second type. It is suggested that important flow-fed sources into the underground masses are the running water in the canals crossing the valley penetrating into the deep hydro-geological routes.

Three general features of soil wetness are part of the uniqueness trait of the Hula Valley: Bulk Density, Wilting Point and Field Capacity:

3.1. Bulk density (BD) and field capacity (FC)

Bulk Density value of soil indicates porosity. If proportionality between pore diameter and porosity exists then porosity is proportional to hydraulic conductivity. Bulk density is inversely related to porosity: the higher porosity in a soil the lower is the Bulk Density.

Field Capacity value indicates soil wetness level, which is potentially removed by gravity and is further dried to the level termed Wilting Point (WP) of which permanent tight Water-Soil Adherence makes water not available.

Consequences to the Hula Valley soil indicates the following: Bulk Density of the Hula Peat Soils was documented as 0.5–0.7 g/cm^3 and the Field Capacity – 75–85% by weight and 48% on a volume basis (Levin, 1970). Three levels of BD (g/cm^3) were indicated for three soil types in the Hula Valley (Litaor et al., 2011/12): Peat: 0.07–0.25; Peat-Lime mineral: 0.25–0.42; Lime-Mineral-(old Lake Hula Bed): 0.42–1.1 g/cm^3. Litaor et al. (2011/12) also indicated water availability (%w/w) of 28 and 107 in the upper (0–25 cm) and deeper (25–50 cm) layers, respectively. Susceptibility of the peat soil to periodical (days, months, years), which might reduce water availability and retention capacity and enhance gravitating migration (Schallinger, 1970; Ravikovitch, 1992; Litaor et al., 2011/12). It should be taken into account that while micro spaces (capillarity) were probably not highly modified during 60 years after the drainage of the valley, preferential pathways capacity was significantly enhanced due to soil degradation and shrinkage. The higher the silt content of the soil texture, the higher is the V% at FC, and WP (V%) is lower and, therefore, gravitating water capacity is enhanced. Consequently, volume and retention capacities were probably enhanced and shortened, respectively, in the Hula Valley resulted by periodical drying/rewetting. Consequently, intensive water

migration capability through preferential pathways in the peat soil became more intensive.

A one year (2004) (Gophen, 1995–2006) water balance of Lake Agmon is presented to exemplify the potential of water migration in the peat soil.

Monthly flow rates measured in 12 stations (Manual Flow-Meter) resulted in the following:

Total Gain————————————————13.8 mcm/y (10^6 m^3 /year)

Total Loss, (including WL increase)———————————— 8.8 mcm/y

Balance (un-measured loss)———————————————— 5.0 mcm/y

The Agmon Bottom area———————————————— –1100 × 10^6 m^2

Suggested conclusive: daily out-infiltration of 12.4 l per m^2.

Average Regional Headwater balances in drought and normal seasons are presented in Table 2:

The following reasons might be considered as causative factors for the dissimilarity of drought seasons: Regional decline of precipitations accompanied by a reduction of legislated usage of water allocation; Progressed agricultural technologies aimed at increased efficiency of water utilization. Results in Table 1 indicates the following incompatibility: During Drought seasons some waters were recorded as headwater inflows but were absent in the measured outflow at Huri bridge and probably were lost between headwater and the valley outflows. Several causation factors were suggested: illegal and, therefore, not

Table 2
Annual Hydrological Balances during 1970–2002: 10 years of drought (1973, 1979, 1986, 1988–19991, 1998–2002) and 12 years (all others) of rainy seasons of water resources in the Kinneret Drainage Basin and losses (consumption and others) (Northern to Huri Bridge) given as annual averages in 10^6 m^3.
(Data. Source: Israeli Hydrological Service)

	Drought	Rainy
Inflow		
River Dan	193	271
River Snir (Hatzbani)	42	128
River Hermon (Banyas)	59	123
All other Rivers	96	132
Total inflow	390	654
Consumption		
Measured	110	130
Unmeasured and/or Losses	38	14
Huri Bridge Outflow	242	510

reported over usage of consumption; infiltration through the principal and intermediate canal bottoms over the entire valley; Evapo-transpiration (ET) from the underground to the atmosphere; Storage in underground free spaces of preferential water pathways. Any combination of the previous assumptions might be relevant. Results in Figs. 2–6 clearly show the significant decline of precipitation and Dan River discharge and the direct relation between those parameters in recent years. On the other hand, a long term (1877- 2010) of precipitation record in Kfar Giladi Station (Fig. 7) indicates less pronounced modification results. Figs. 8–10 indicate the increase of water "consumption" accompanied by the decline in water availability in winter in the basin during drought seasons.

The sense of the factor value of Alfa (ϱ) (Figs. 9–11) is the following:

Alfa = (V/X) * 100; The 100 multiplication is aimed at scale plot adaptation.

Where:

V = Available water inflow from the Drainage Basin in winter

X = Precipitation (mm).

The predicted value of available water in Lake Kinneret in Summer in relation with Alfa value is exponential (Fig. 11): When Alfa value declines from 110 to app 80, the corresponding value of summer water availability sharply declines from 200 to app 75 mcm whereas Alfa decline on the lowest level (80–40) corresponds to a lower decrease in its availability in summer probably due to water loss enhancement in the valley. A confirmation of the underground water flows in the preferential pathways is shown in Photo 1.

The long-term record of hydrological data in Israel (Givati,

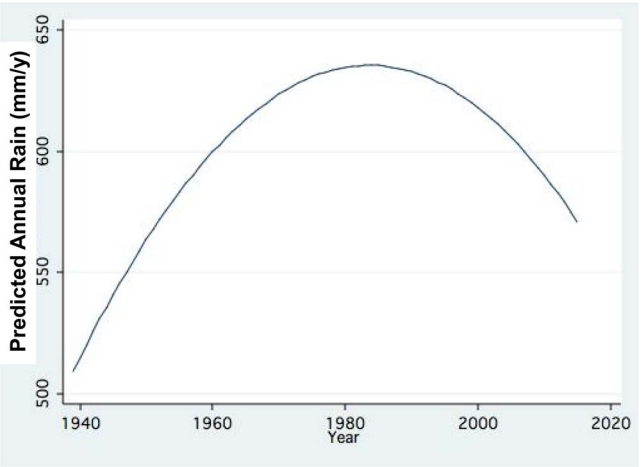

Fig. 2. Fractional Polynomial Plot of Annual Rain (Dafna) (mm) (1939–2015).

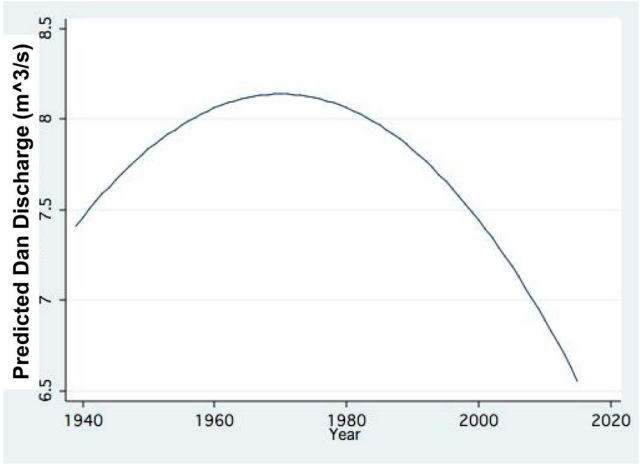

Fig. 3. Fractional Polynomial regression of Annual average of Dan Discharge (mˆ3/s) during 1939–2015.

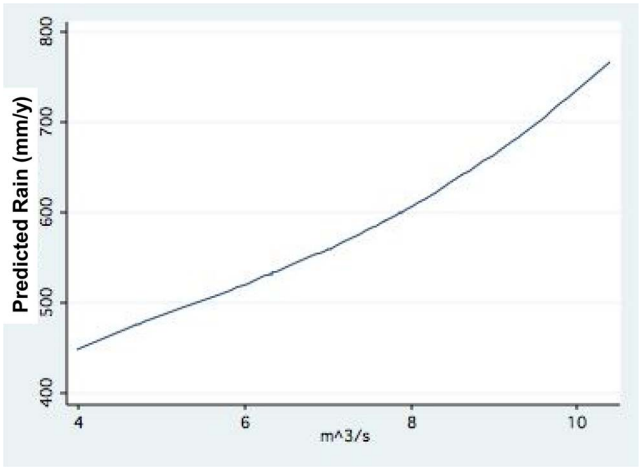

Fig. 4. Fractional Polynomial Regression of Annual Rain (Dafna) (mm/y) vs. Dan Discharge (mˆ3/s)(1939–2015).

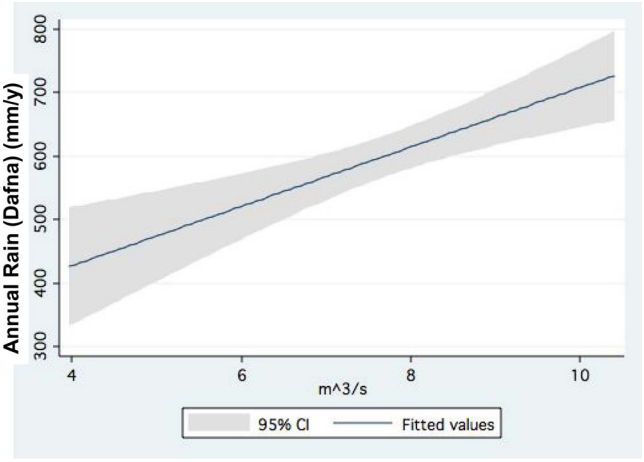

Fig. 5. Linear Regression between Annual Rain (Dafna) (mm/y) and annual mean of Dan Discharge (mˆ3/s) (1939–2015) 95% CI is indicated, p = 0.0001; rˆ2 = 0.1776.

1970–2016) confirmed a trend of precipitation and river discharge decline in the Kinneret drainage basin. During 2013/14 and 2015/16, annual precipitations were 47% and 53% of the multiannual average, respectively. Rain declined in the Golan Heights from an average of 954–708 mm/y recently; the lowest discharge in the Dan River ever

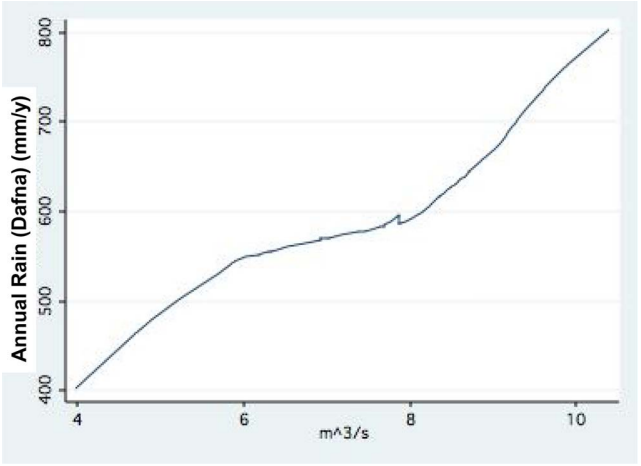

Fig. 6. LOWESS (0.8) Regression Plot of Annual Rain (mm) (Dafna) vs. Dan Discharge (mˆ3/s) (1939–2015).

recorded was 2.7 m^3/s and similarly in the Baniyas River 0.16 m^3/s and in the Jordan River 2.5 m^3/s. Moreover, total annual discharge in the Dan River decreased during the last 3 years by app. 100 mcm/y and, in the Jordan River, a decline from the normal range of 300–400 to 150 mcm/y was documented during the last 3 years. Conclusive assumption considers the decline of the River Jordan discharge as partly due to water loss in the undergrounds of the Hula Valley enhanced by climate dryness trend.

4. Discussion

The indication of dryness trend in the northern part of Israel and the obvious prominent relation between rain and river discharges is widely acceptable and significantly confirmed for the last 3–5 years. Nevertheless, statistical analysis of the rain and discharge record emphasizes some discrepancy results: The total average (1939–2015; 76 years) of precipitation record in northern Hula Valley (Dafna Station) is 602.3 mm/y: In 39 years rain gauge was below the average and in 37 years was above it. The total average (1939–2015) of the Dan River Discharge was found to be 7.72 m^3/s, and in 32 years discharge was below the average and in 44 years was above it. Consequently, the dryness trend might be presently too short to be concluded as a long-term change.

The confirmation of water loss in the Hula underground mostly during the dry seasons is partly indirect. Nevertheless, the peat soil properties and “behavior” during cycles of periodical dryness and wetness management and field observations justify conclusive remarks of micro and macro scale porosity. The vertical and horizontal migration of water mass through underground free spaces of cracks, tunnels and other configurations can, therefore, be confirmed. The volume of lost water is, therefore, related to the soil dryness level: the more (longer term) it is dry the greater is the volume of water loss.

It was previously documented (Litaor et al., 2011/12) that available and gravitating water in the peat soil when moisture fluctuates between FC and WP represents the following values: Upper limit (FC) of 107–129% (w/w) whilst after dryness 21–43% (w/w). Consequently, moisture removal by gravitation together with ET is 86%. It was also documented that in the southern part of the valley where soil is classified as Peat-lime mineral and Lime-mineral (Litaor et al., 2011/12), FC and WP levels represent lower capacity and, therefore, the flow rate of the migrating portion is more intensive and restricted to preferential pathways. The soil volume capacity of 30×10^6 m^2 surface area of the northern Peat soil part in the Hula Valley multiplied by depth layer of 1.6 m (maximal decline of Underground water table) (Gophen et al., 2014) resulting in 48 mcm, and 86% (41.3 mcm) of it are due to

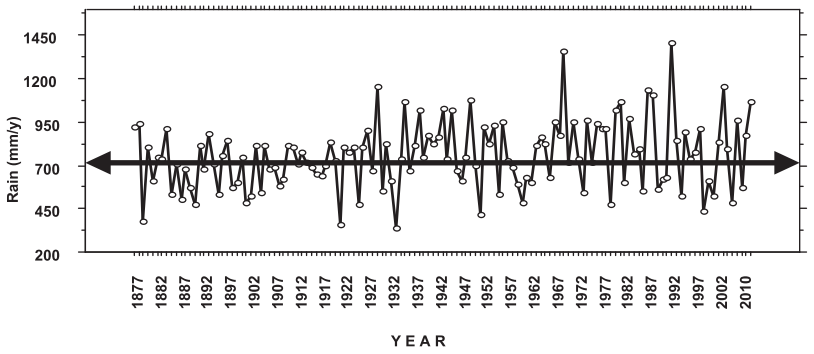

Fig. 7. Annual Rain Gauge 1877–2012: Kfar Giladi 1926–2012; Beirut Simulation 1877–1926 Multiannual Mean is arrowed.

migrated waters and ET.

One prominent factor within the water supply management program for the upper Galilee does not make sense: Figs. 1–6 clearly indicated a decline of Rain capacity and headwater discharges in the Kinneret Drainage Basin although Fig. 7 does not confirm a similar rain decline trend in the West-Northern region (Beiruth-Kfar Giladi). Nevertheless, Figs. 8–11 indicate higher water "consumption" in the northern part of the Kinneret Basin. Data about water supply regulations as legislated by the national water authorities are not presented here as a result of incomplete documentation but (personal communication) restrictions were clearly constrained. It is, therefore, concluded that missing water capacities were indicated incorrectly as "consumption". It is probably a misleading indication. Water capacity in the Hula outflow through the River Jordan has declined, but the missing capacities are probably due to underground loss. Berger (2001) documented the available water decline during 1980–1990 by a 27% reduction of River Jordan discharge accompanied by a sharp increase in water consumption which was leveled at 170 mcm/y. Linear regression (Berger (2001)) between Time and "consumption" indicates a significant increase ($r^2 = 0.81$; $p = 0.0001$). Rom (2001) documented a significant decline (35%) of available Kinneret waters. Schanzis (2002) concluded a decrease (38%) of Kinneret available waters where 22% are due to precipitation and Run-Off factor (Run-Off capacity divided by Precipitation) decline, and 16% decrease are due to increased consumption. Consequently, water consumption north of Kinneret has increased from 100 to app 200 mcm/y, mostly in dry seasons. Scientists and engineers from the Water Planning for Israel (TAHAL Co. Ltd.) carried out a 7 year (1989–1996) survey (Personal Commun.) of water consumption in the northern part of the Kinneret Drainage concluded

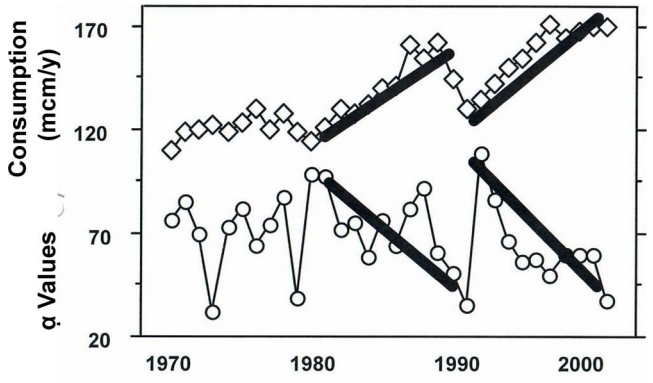

Fig. 9. Lower line (open circle): α = (V/X) * 100; V = winter available water (mcm); X = Precipitation (mm); Upper Plot: Water Consumption Northern to Huri Bridge (mcm/y) Trend of changes are indicated (solid plot).

by an average value of 129 mcm/y. A special report carried out by the Agricultural Ministry concluded by a similar value of 127 mcm/y. The essence of the present paper is the acceptance of the significance of the potential impact of underground gravitating water loss. It conclusively explains the difference between the high (Berger, 2001; Schanzis, 2002) and low levels (TAHAL 1989–1996; Agriculture Ministry) of consumption value.

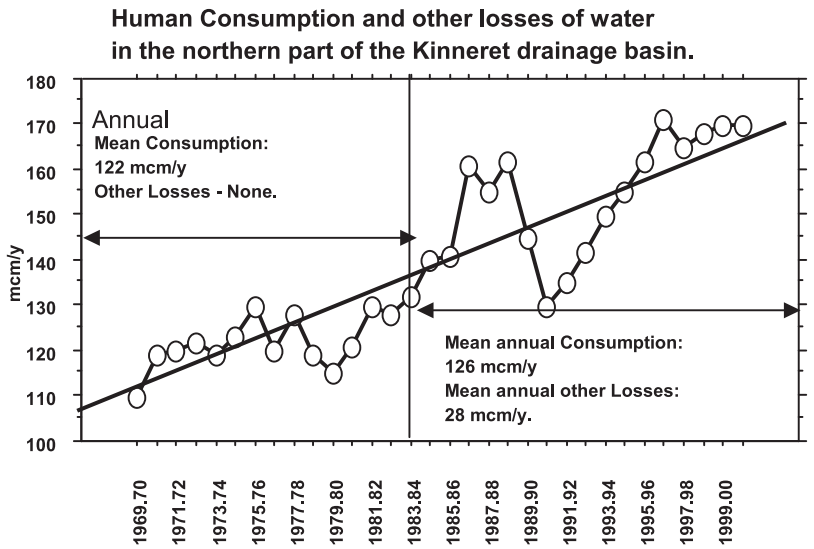

Fig. 8. Linear regression between water Consumption, including losses and time Regression line is indicated (solid plot: $r^2 = 0.731$; $p < 0.0001$).

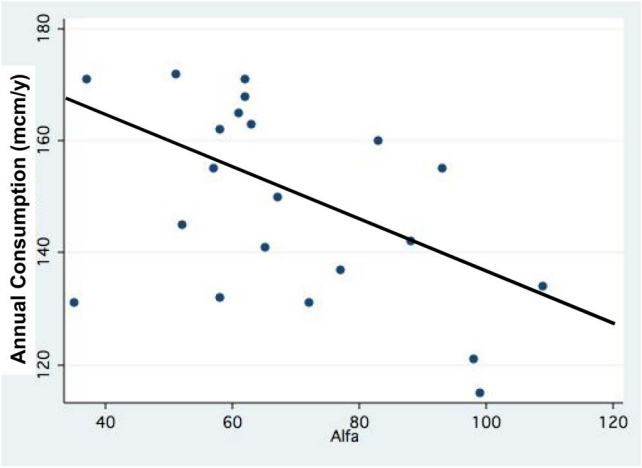

Fig. 10. Linear Regression (solid plot) (r^2 = 0.239; p = 0.0209) between ɑ values (see text) and annual water consumption,including losses, in the Kinneret Drainage Basin north of Huri Bridge.

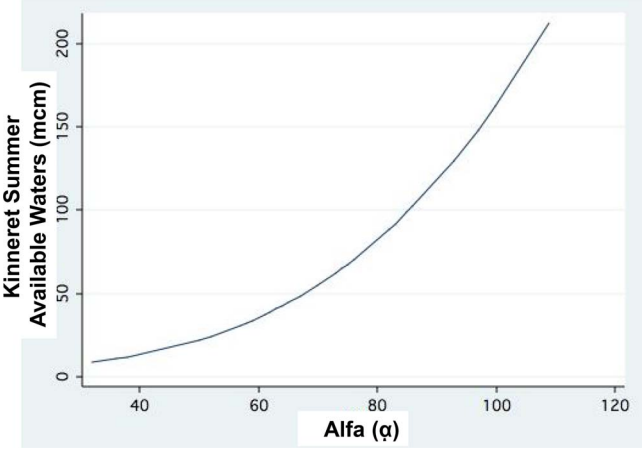

Fig. 11. Fractional Polynomial Regression (r^2 = 0.518, p < 0.0001) Between ɑ values (see text) and Summer (April–September) values of Kinneret Available waters (Inflow minus Evaporation).

5. Conclusions

To reduce water loss in the Hula Valley, especially during recent dryness conditions, it is recommended to keep high levels of soil moisture. Climate change expression in the northern Kinneret Drainage region is precipitation decline and headwater rivers decline of discharge. Soil classification in the Hula Valley includes northern organic peat and southern Peat-Lime Mineral. Seventy years after the Hula drainage and dryness, rewetting periodical cycle creation of preferential gravitating water lines intensify water loss capacities. Optimal management of soil moisture might, therefore, reduce underground free space enhancement and suppress water loss.

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